Dependence of Radiative Forcing on Mineralogy in the Community Atmosphere Model

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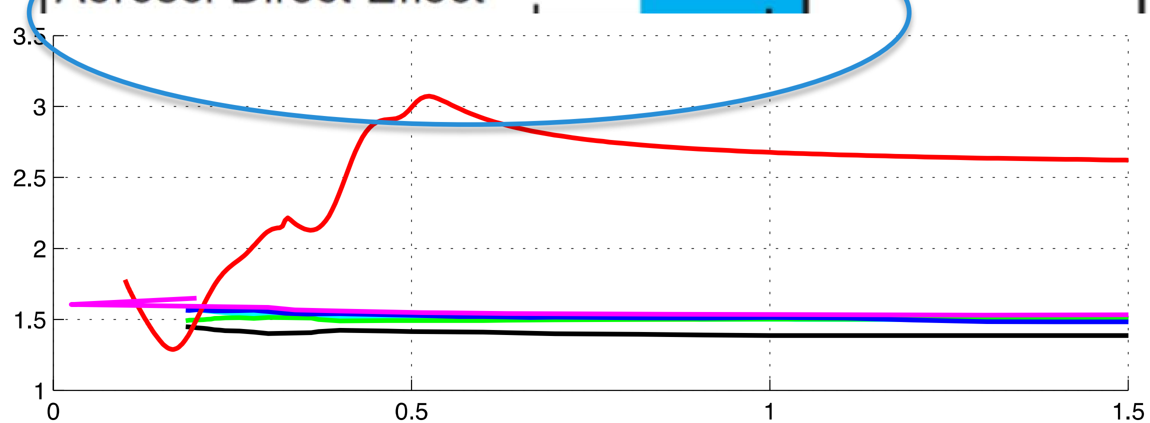
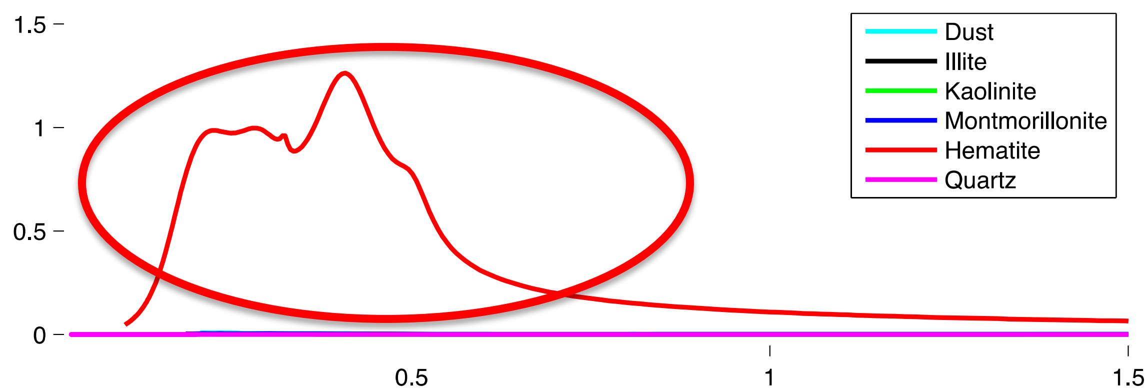
Motivation

Refractive index: the ratio of velocity of light in a vacuum to the velocity of light through a material and is a function of the wavelength of light.

Imaginary component corresponds to the absorbing nature of the material





- **Aerosols influence the Earth's radiative budget by directly scattering and absorbing incoming short-wave (SW) radiation and outgoing long-wave (LW) terrestrial radiation**

- **Scattering and Absorption of radiation influenced by particle size and composition**

- **Iron oxides ie hematite controls magnitude of absorption in SW**

Refractive indices
Dust: Mahowald et al. 2006
Illite, Kaolinite, Montmorillonite:
Egan and Hilgeman (1979) (0.18-2.5µm)
Querry (1987) (2.5-50µm)
Hematite: A.H.M.J. Triaud (0.1-47µm)

Methods: CAM4

- Aerosol species are externally mixed
  - Individual particles are composed of a single species
- Prescribed size distribution
  - Number diagnosed from mass
    - Processes that should only affect mass also affect number (condensation, chemistry)
    - Processes that only affect number are neglected (nucleation, coagulation)

Bulk Aerosol Model (BAM)

ammonium | **sulfate**

oc-hydrophobic | **bc-hydrophilic**

8 minerals x 4 bins = 32 dust tracers!

Gypsum
Feldspar
Hematite
Calcite / **Sea salt 1**
Quartz
Montmorillonite
Kaolinite / **Dust 1**
Illite

Sea salt 2 | **Sea salt 3** | **Sea salt 4**

Dust 2 | **Dust 3** | **Dust 4**

.1µm ↔ 1.0µm ↔ 2.5µm ↔ 5.0µm ↔ 10µm

Methods:CAM5

Modal Aerosol Model (MAM)

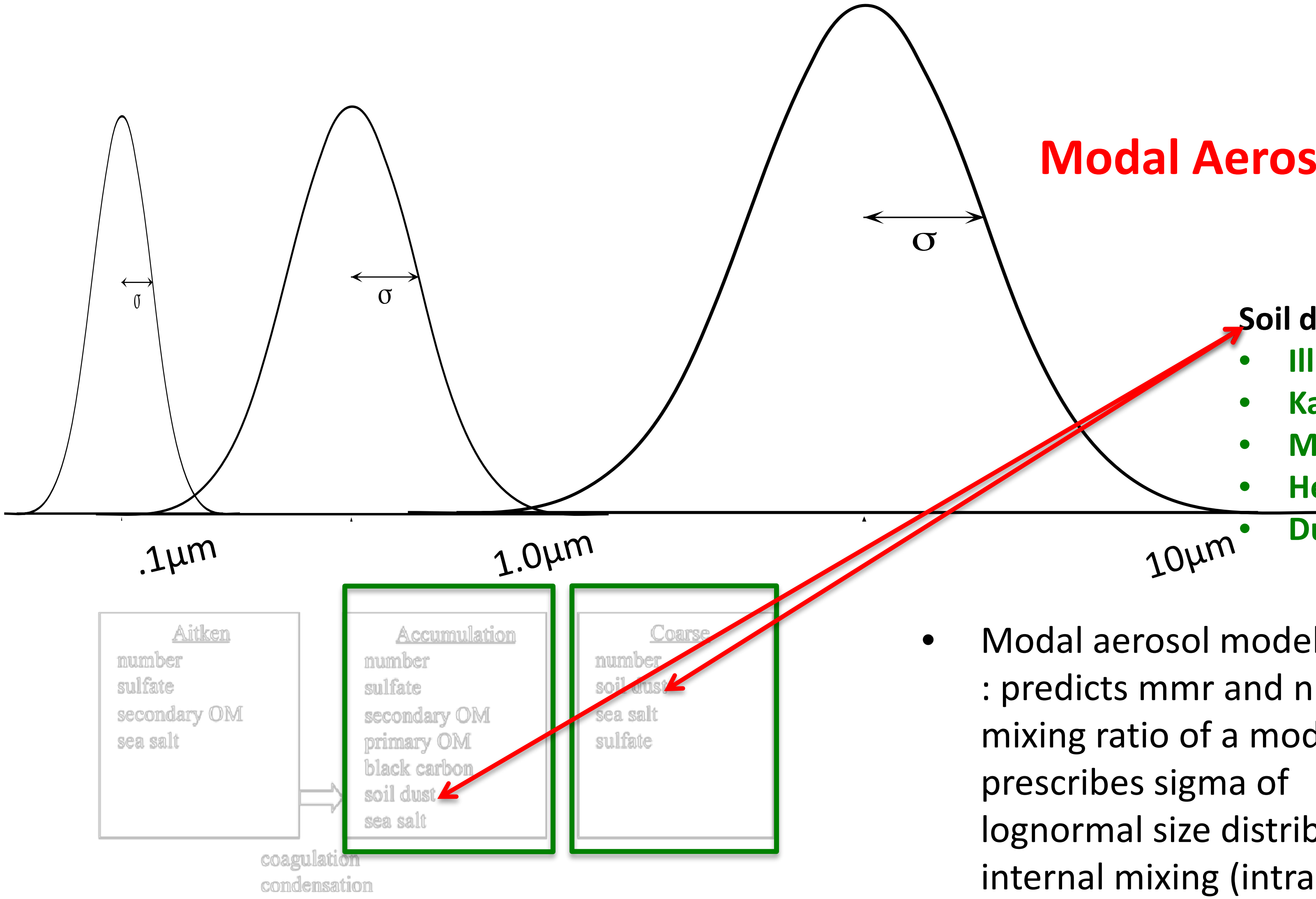


Fig. 2. Predicted species for interstitial and cloud-borne component of each aerosol mode in MAM3. Standard deviation for each mode is 1.6 (Aitken), 1.8 (accumulation) and 1.8 (coarse mode).

Soil dust =

- **Illite**
- **Kaolinite**
- **Montmorillonite**
- **Hematite**
- **Dust$_{Other}$**

- Modal aerosol model (MAM) : predicts mmr and number mixing ratio of a mode, prescribes sigma of lognormal size distribution, internal mixing (intra-mode) & external mixing (inter-mode)

Methods: CAM4 and CAM5

- **CAM4 has 8 minerals while CAM5 has 4??**
- I can compare these because we only modeled optically the minerals common to both models.
  - Quartz, Gypsum, Feldspar and Calcite in CAM4 and "rest of dust" in CAM5 are optically modeled as a non-absorbing dust blend.

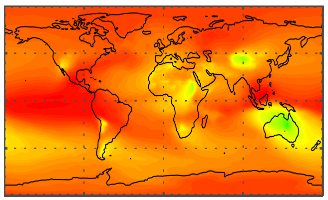
- Both CAM4 and CAM5 with just dust have been optimized and are referred to throughout this presentation as **"tuned"**. ***Note, mineralogy runs employ same tuning parameterizations with the addition of mineral speciation

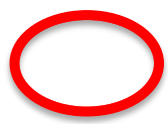
- Tuning:
  1. Dust source emissions have been tuned to match observations (Albani et al., submitted;Mahowald et al., 2006)
  2. Particle size distribution at emission follows the brittle fragmentation theory of dust emission from Kok 2011
  3. Scavenging coefficients, particle solubility and leaf area index have been optimized (Albani et al., submitted)
  4. Refractive indices changed from OPAC to optics from Mahowald et al., 2006

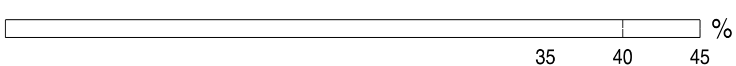
Results: Total column mineral distribution

- Simulations run with GEOS5 meteorology from 2004-2011, analysis uses the last six years (2006-2011)
- Percent of mineral in the atmosphere, total column dust mixing ratio. The distributions for the models forced with identical source distributions but the physics of transport and deposition differ between CAM4 and CAM5

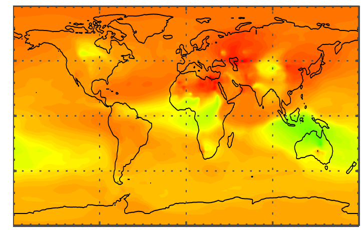
CAM4

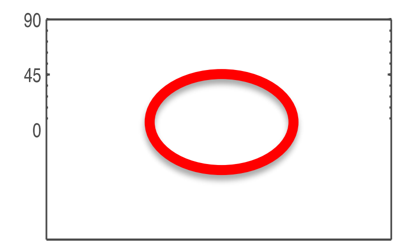


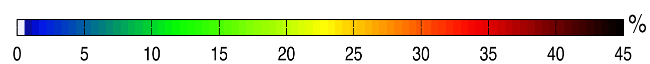




CAM5



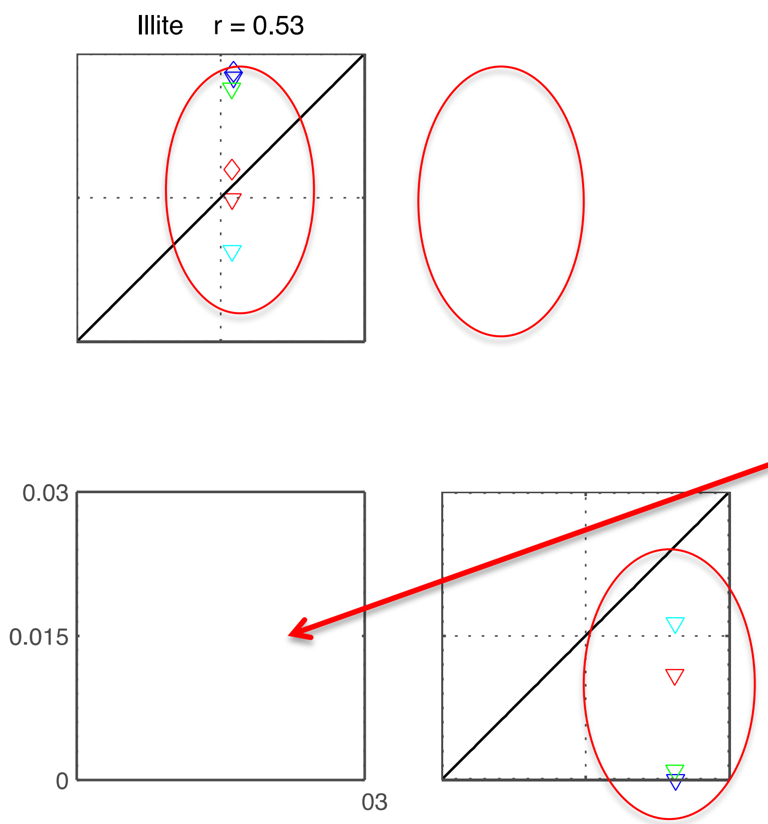


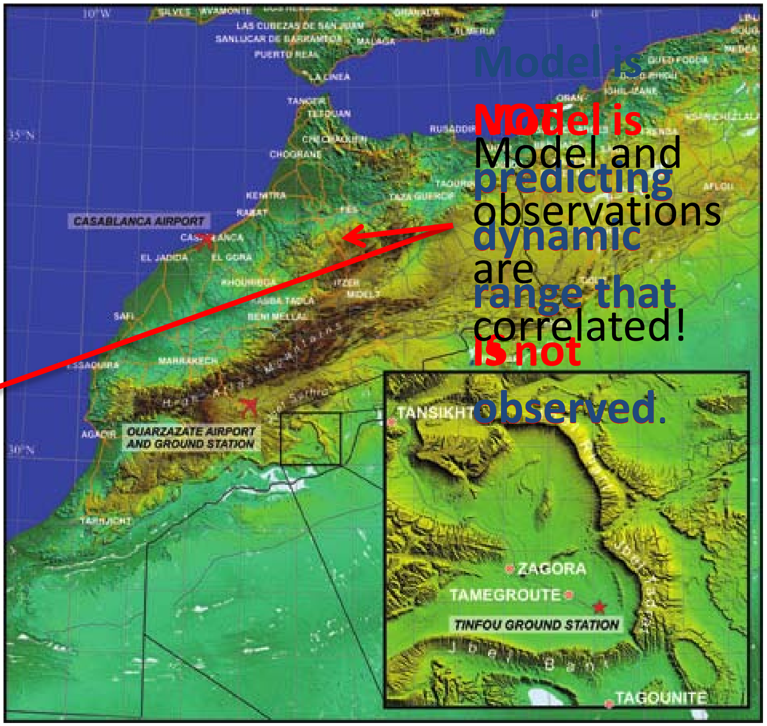


- Hematite concentrations over N. Africa are low in CAM4 and higher in CAM5

Results: Comparison to Observations

- Relative mass abundance of minerals as modeled compared to observations from Kandler et al., 2009 for CAM4, bins 1-4 and CAM5, mode 1 and mode 3.





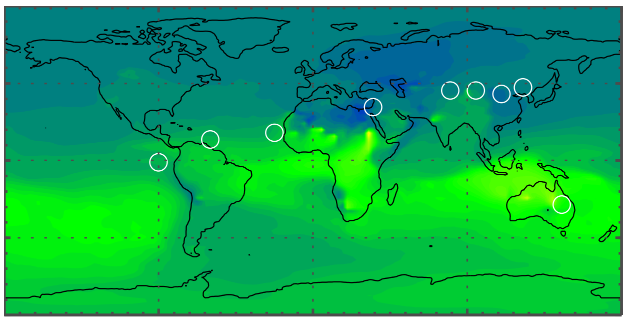
Model is NOT predicting dynamic range that is not observed.

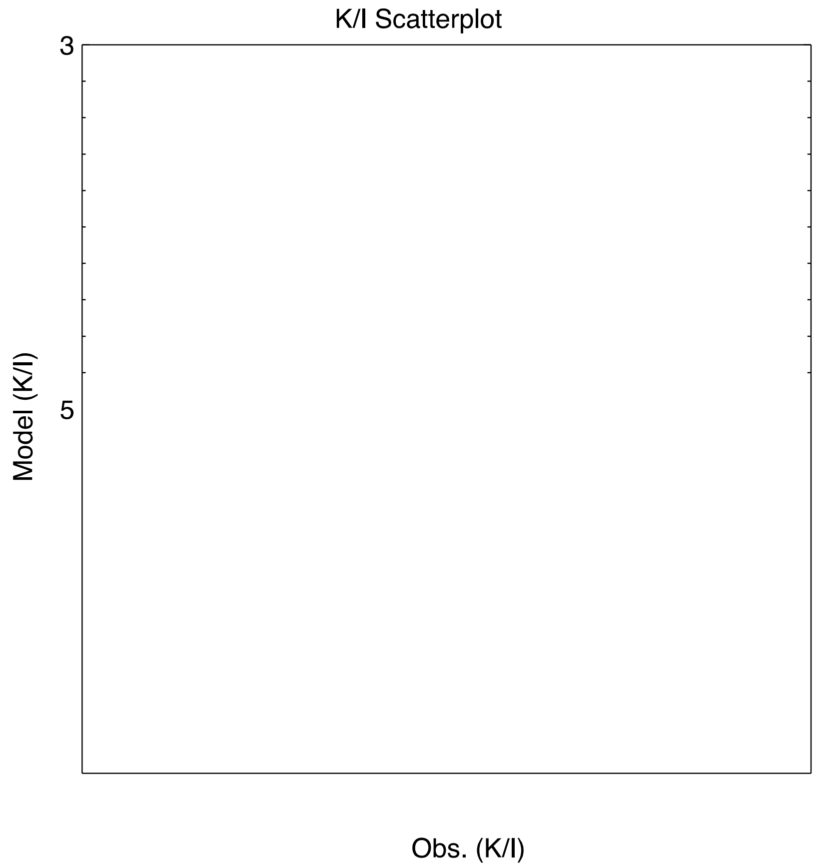
Model and observations are correlated!

Fig. 1. Northwestern Africa and the Atlas mountain range in Morocco. The detail map shows the region of the Tinfou ground station. Kandler et al., 2009

Results: Mineral Ratio comparison

Kaolinite/Illite





- For most observations, particle size distribution is not given
  So we compare the **ratio** of minerals with similar sizes

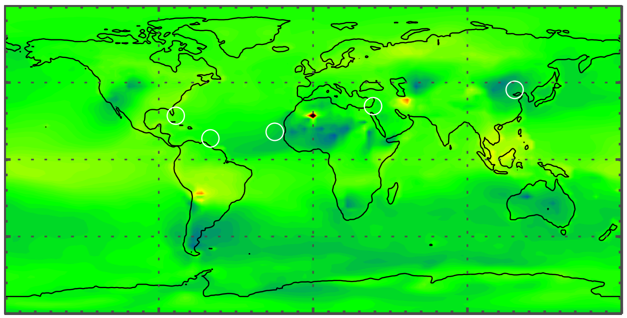
Daily averaged model output shows temporal range more similar to range seen in observtions

Model not capturing the dynamic range seen in observations

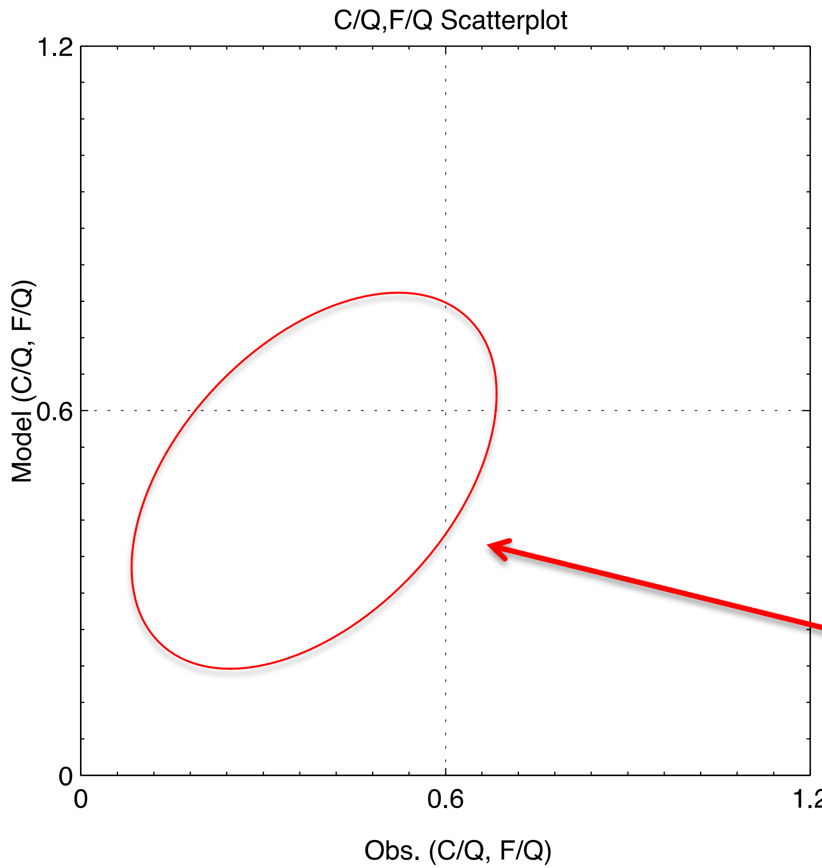
Kaoline/Illite mineral ratio of mineral mixing ratio at the surface from CAM4 and CAM5 (kg K/kg I) compared to bulk obervational ratios. Observations from Shen et al., (2005), Prospero and Bonatti, (1969), Caquineau et al. (1998), Kiefert et al., (1996), Falkovich et al. (2001).

Results: Mineral Ratio comparison

Calcite/Quartz and Feldspar/Quartz



Ratio

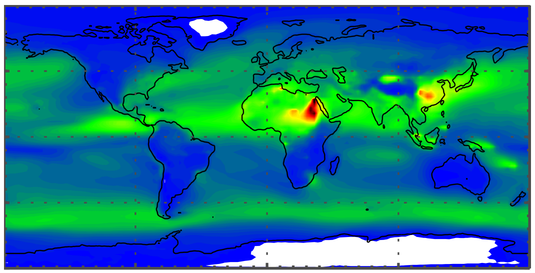


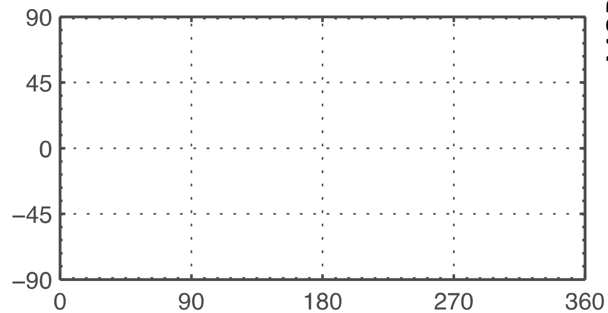
Again notice lack of dynamic range in monthly averaged model data

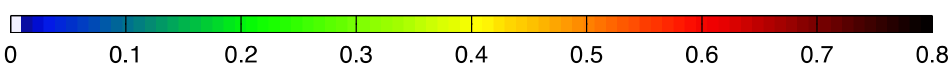
Daily averaged model output shows some improvement

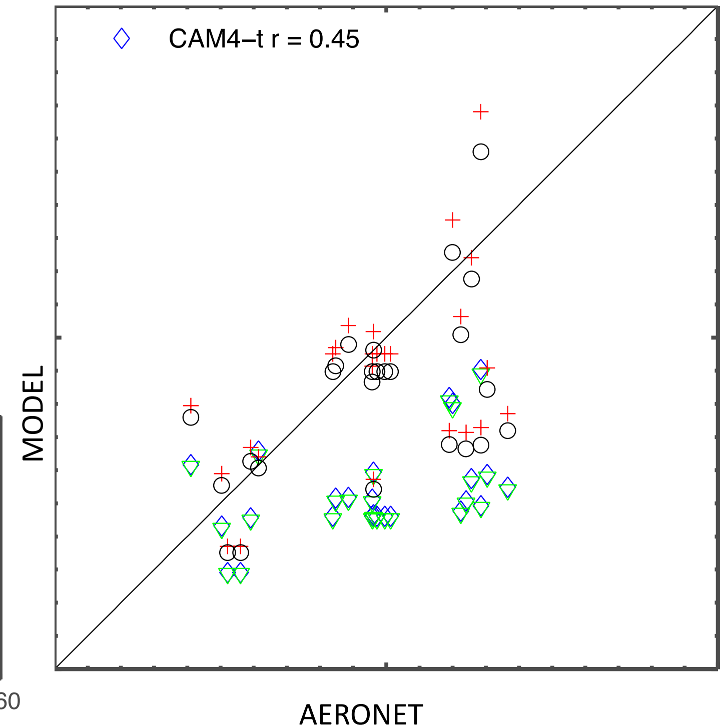
Calcite/Quartz and Feldspar/Quartz mineral ratio of mineral mixing ratio at the surface from CAM4 and CAM5 (kg K/kg I) compared to bulk obervational ratios. Observations from Glaccum and Prospero (1980), Prospero and Bonatti, (1969), Falkovich et al. (2001), Shi et al., (2005).

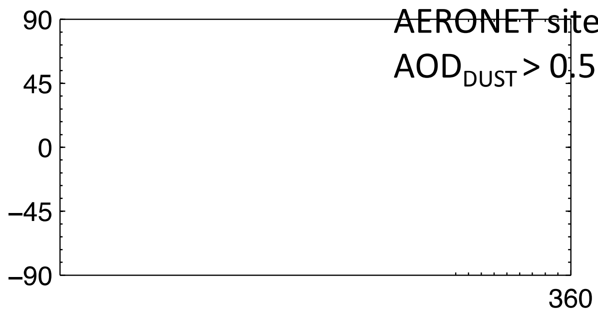
Results: AOD AERONET vs Model



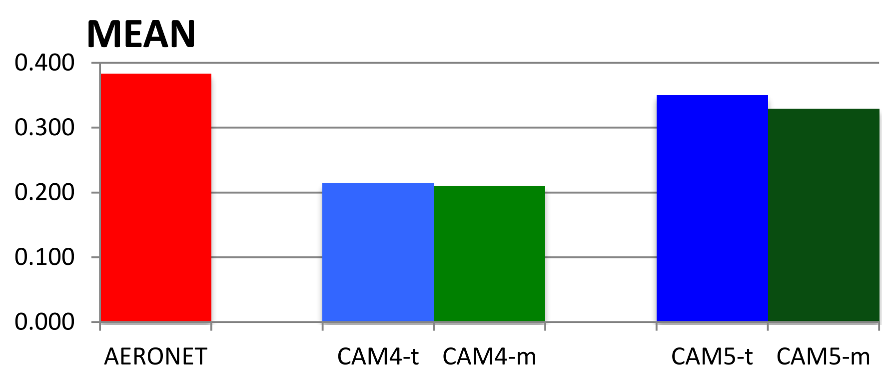




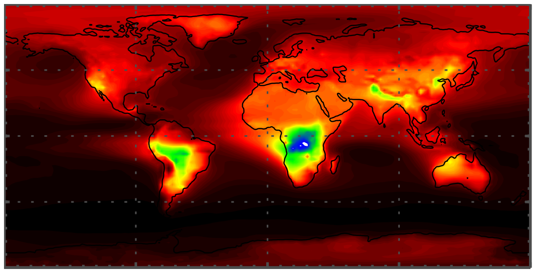


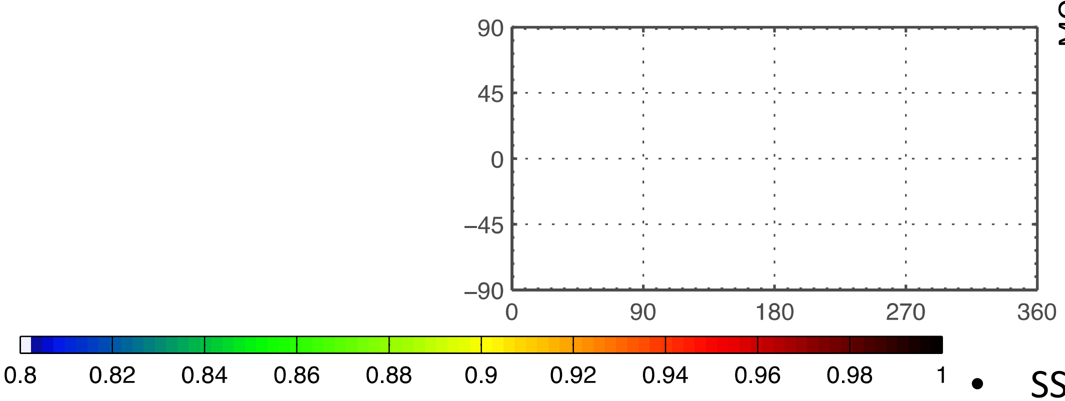


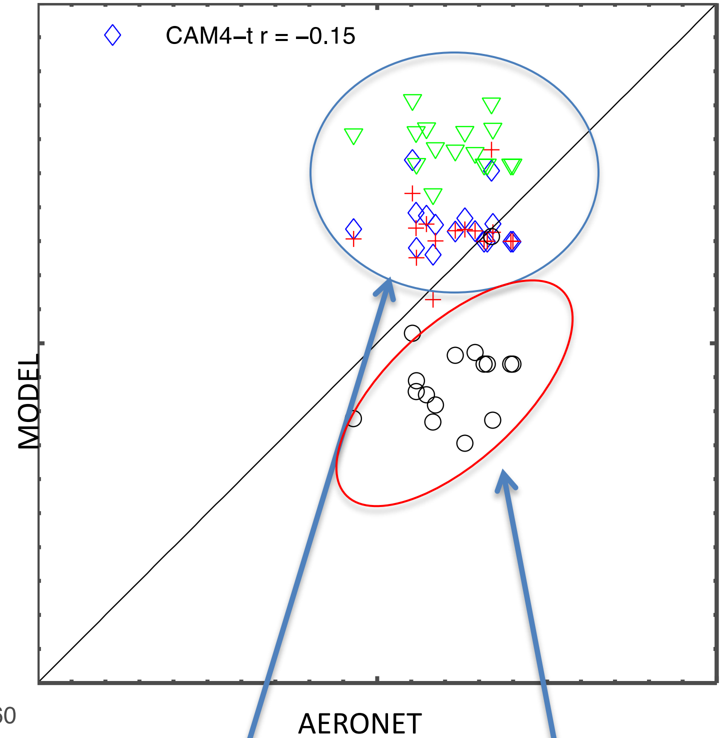
Pink dots correspond to AERONET sites where $AOD_{DUST} > 0.5 * AOD_{TOTAL}$

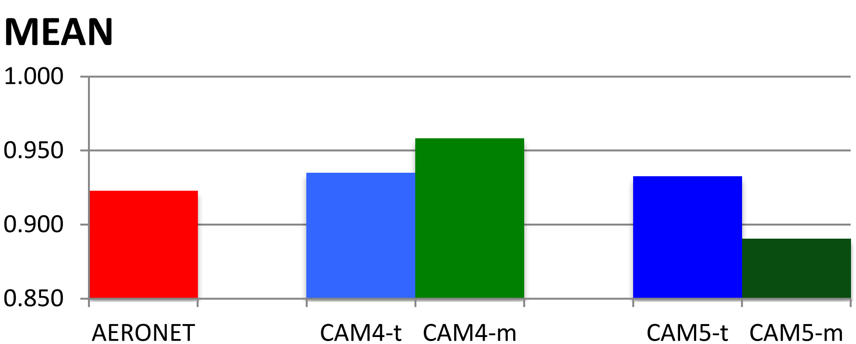


Results: SSA AERONET vs Model



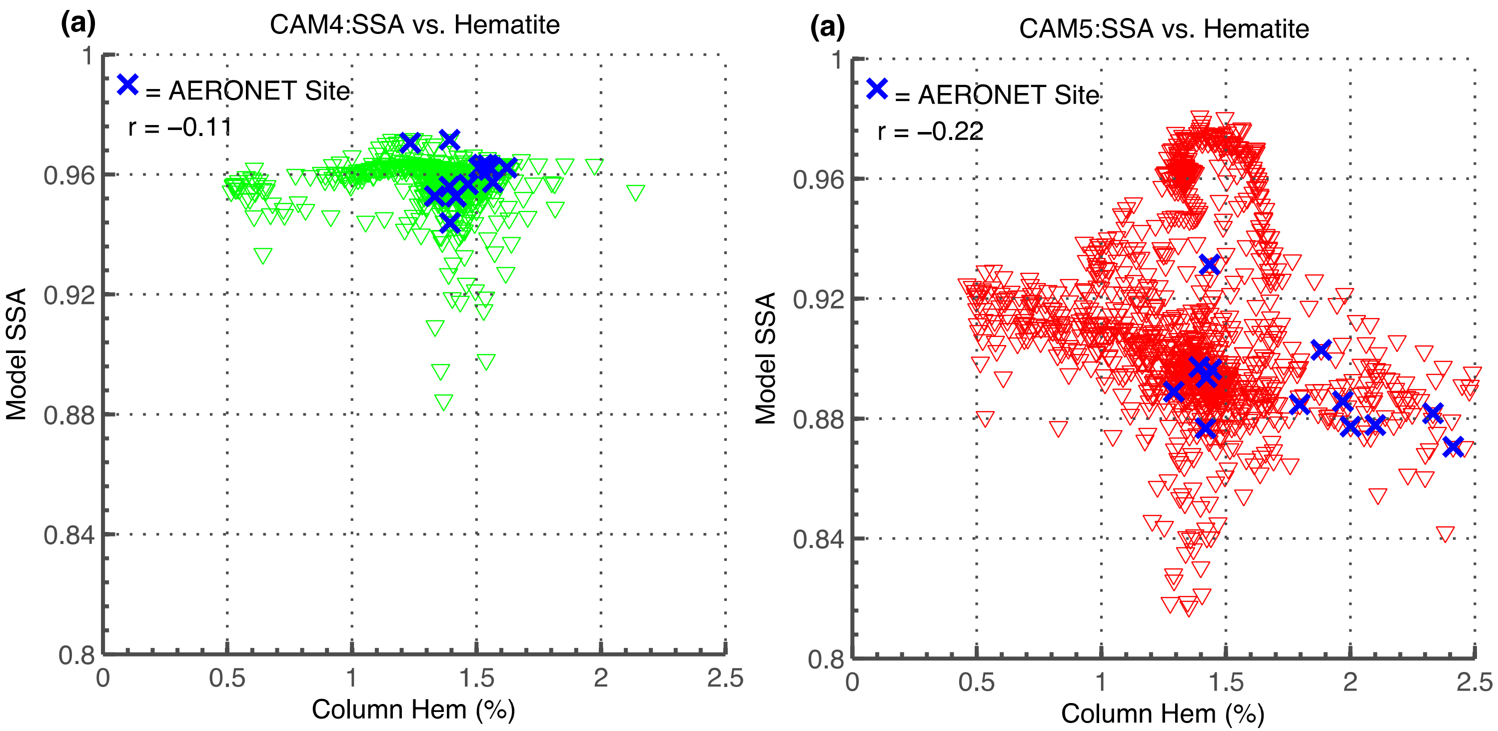






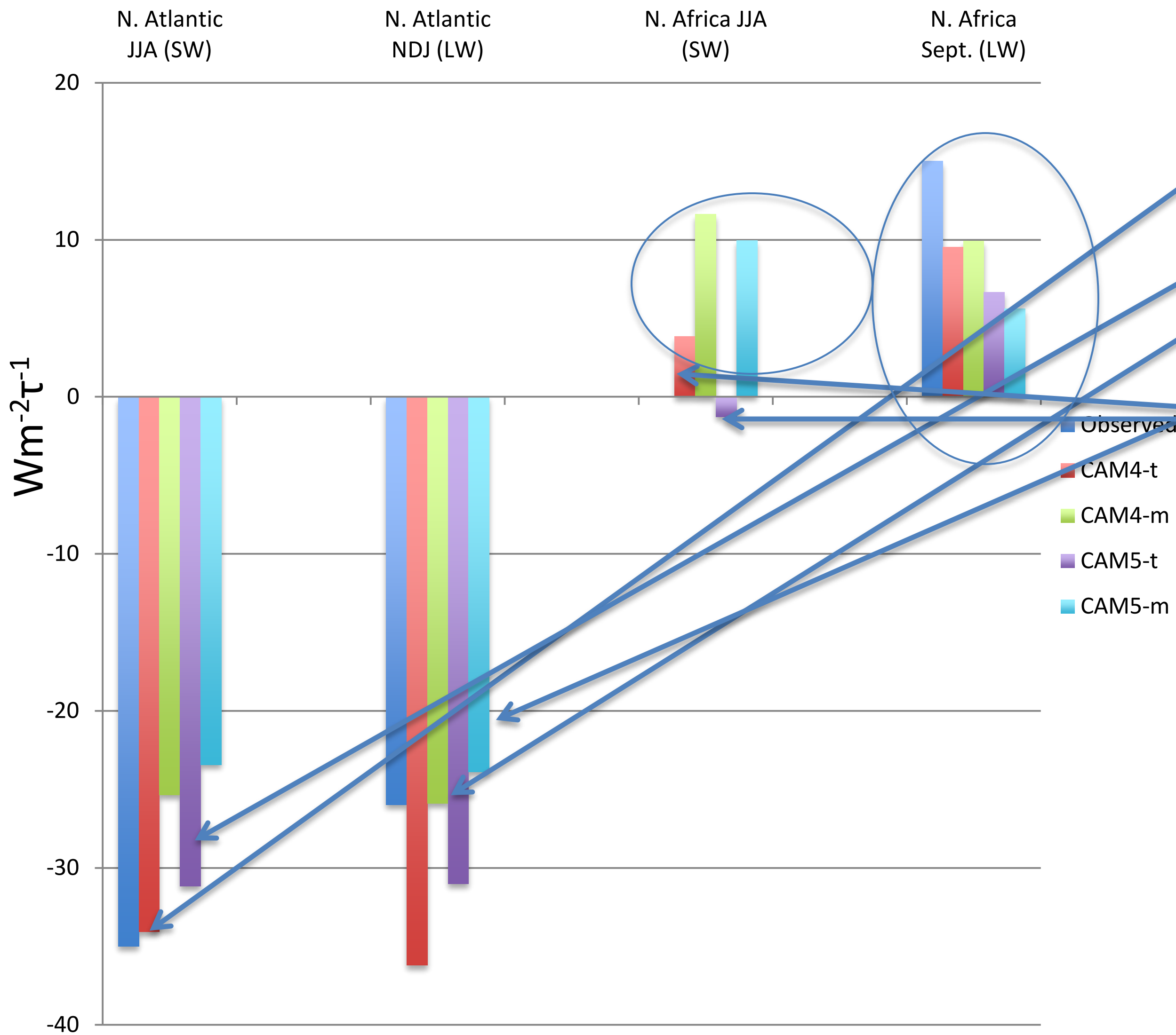
- SSA controls the amount of absorption vs scattering of particles, hematite and black carbon have very low SSA→ they dominate the absorbing nature of aerosols
- Note lack in dynamic range for CAM4t, CAM4m and CAM5t
- CAM5m is too absorbing, however it better captures the range seen in AERONET

Results: SSA CAM4 and CAM5



- Model Single Scattering Albedo in CAM4 and CAM5 mineralogy is compared to total percent column hematite. The location of **AERONET sites** used in the previous slide are plotted in blue.
- CAM5 has more hematite: significant decrease in SSA

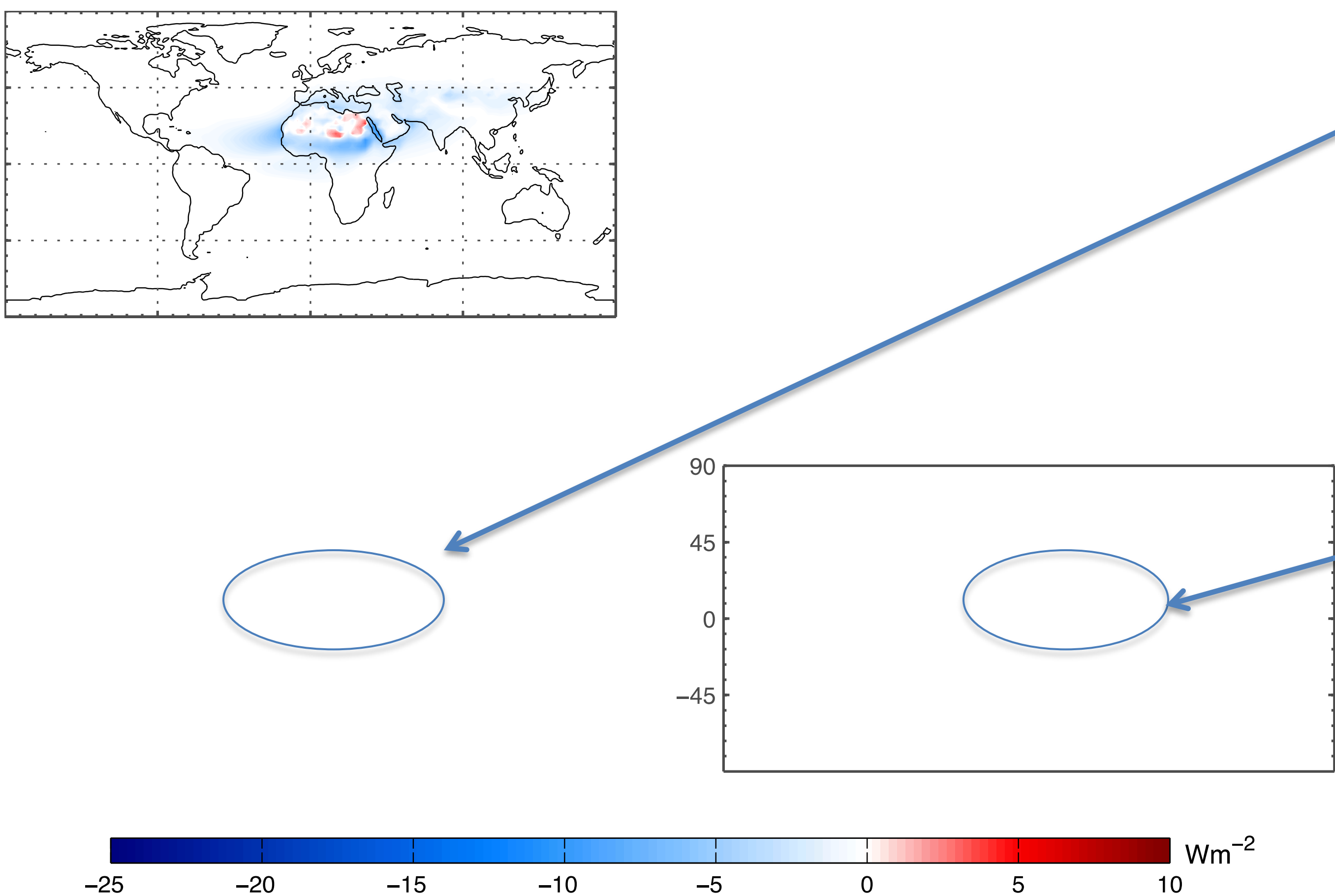
Results: Radiative Forcing Efficiency



- Observations from Li et al., 2004 over N. Atlantic:
  - CAM4t and CAM5t match observed during summer
  - CAM4m and CAM5m match during winter
- Patadia et al. observed RFE of zero over N. Africa summer
  - CAM4t and CAM5t are close to 0
  - CAM4m and CAM5m predict heating
- Chistopher and Zhang (2004) estimate LW RFE during September
  - Quartz dominates LW absorption but this property has not been included
  - All model simulations neglect scattering in LW

Results: All-sky Radiative Forcing

- All-sky radiative forcing is a measure of the radiation balance from the scattering and absorption of incoming solar radiation and diffuse long wave radiation from the Earth's surface for both clear and cloudy conditions



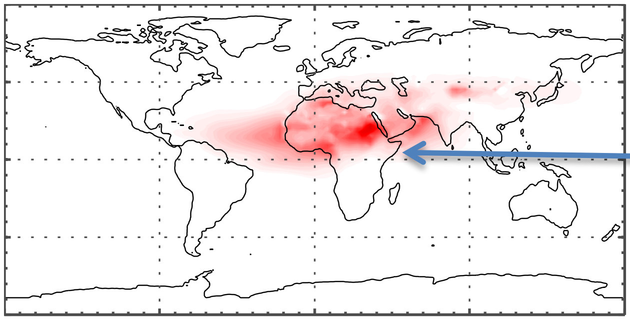
Less cooling at surface in CAM4m→ CAM4-t is more absorbing hence cools more

Significant cooling at surface in CAM5m → absorbing hematite decreases insolation reaching surface

Spatial distribution of annual all-sky radiative forcing (SW+LW) at the surface for CAM4 with tuned dust and with mineralogy (a,c) and for CAM5 with tuned dust and mineralogy (b,d).

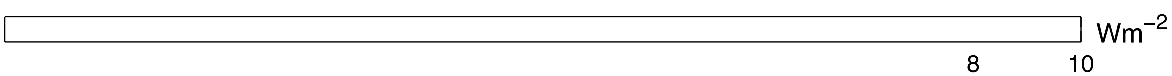
Results: All-sky Radiative Forcing

Spatial distribution of annual all-sky radiative forcing (SW+LW) in the atmosphere (ATM) for CAM4 with tuned dust and with mineralogy (a,c) and for CAM5 with tuned dust and mineralogy (b,d).



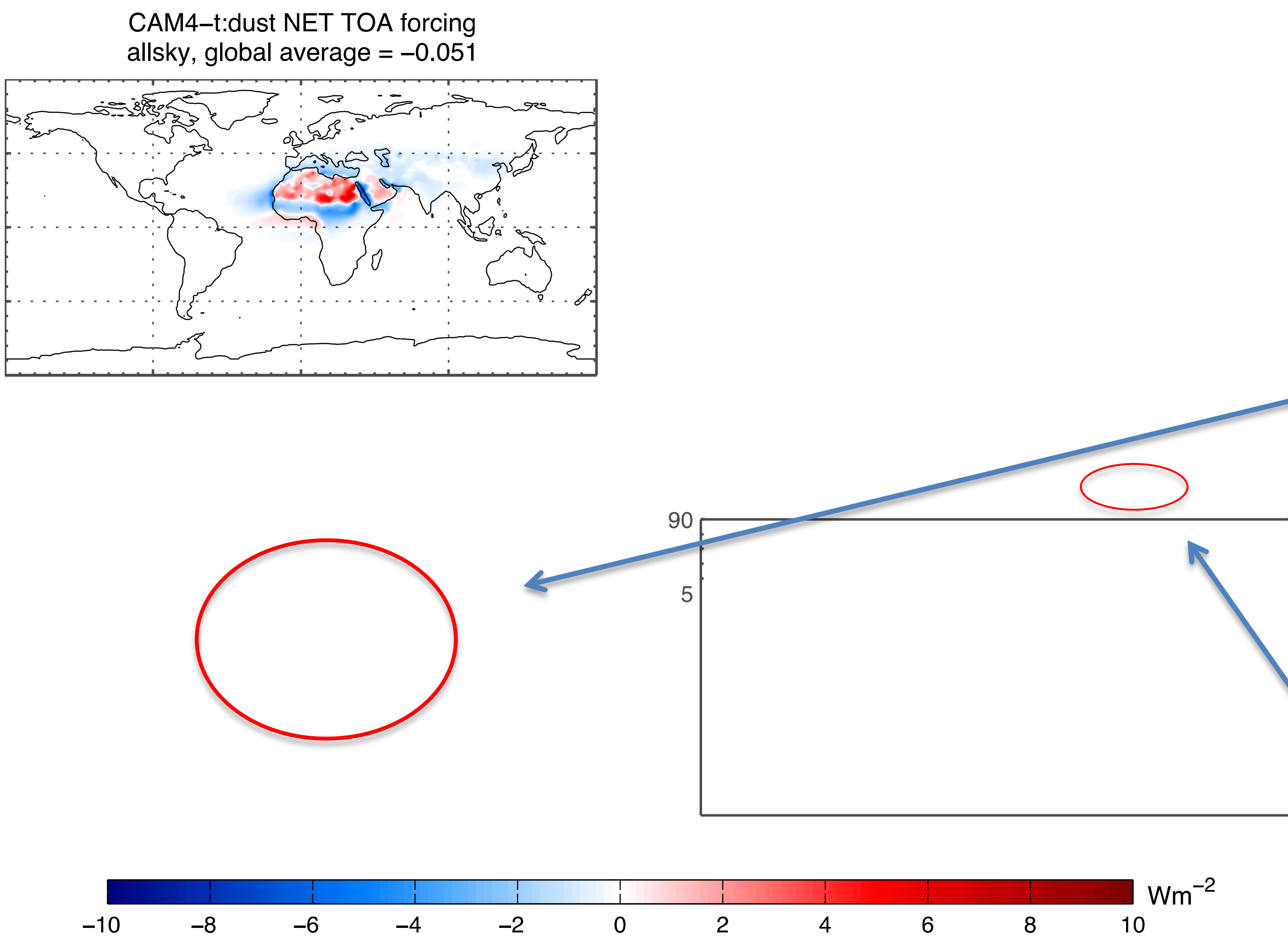
Similar heating in CAM4t and CAM4m

CAM5m → absorbing hematite results in 3X the heating in the atmosphere compared to CAM5t



Results: All-sky Radiative Forcing

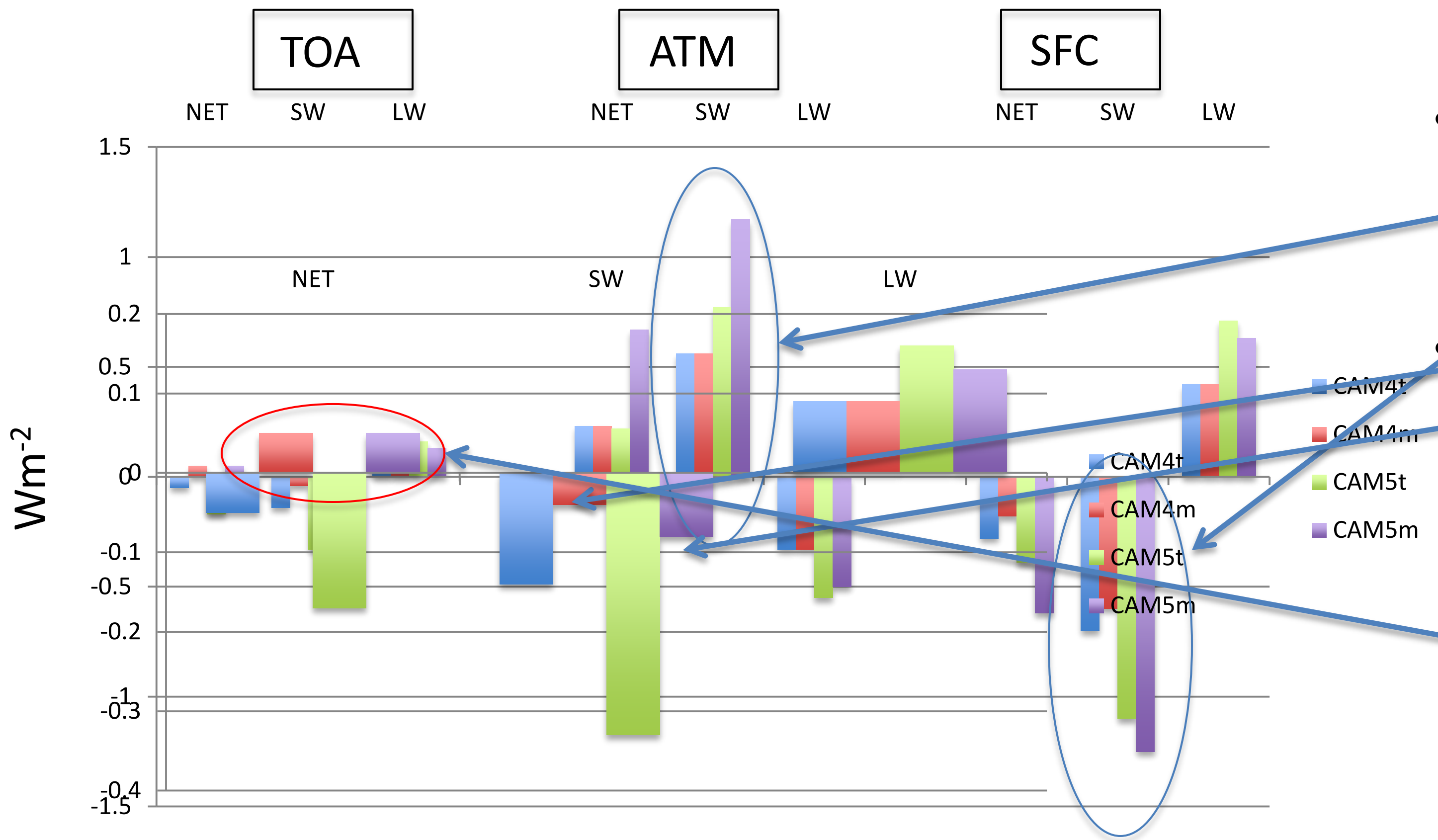
Spatial distribution of annual all-sky radiative forcing (SW+LW) at the top of atmosphere (TOA) for CAM4 with tuned dust and with mineralogy (a,c) and for CAM5 with tuned dust and mineralogy (b,d).



- Similar atmosphere RF for CAM4t and m however differences in surface forcing lead to an overall heating at TOA
- Increased cooling at surface in CAM5m is compensated by increased atmospheric heating and an overall positive forcing at TOA

Results: Mean All-sky Radiative Forcing

Globally averaged radiative forcing at TOA is a delicate balance between SW and LW forcing at the surface and in the atmosphere



- SW forcing dominates ATM and SFC forcing
- While CAM4m and CAM5m in SW has a small negative forcing at TOA, the overall impact from SW and LW is small positive heating

Conclusions

- Built and implemented infrastructure in CAM4 and CAM5 to carry multiple dust types (i.e. minerals)

- The first goal with this was to simulate the direct affect of adding mineralogy
  - The conclusion? We need more data! Better source mineralogy maps!
  - Which parameters are most important for simulating DRE?
    - PSD, Mineralogy, Optical properties (AOD, SSA)
  - CAM4 size is probably more important than mineralogy
  - CAM5 mineralogy may actually help simulate direct effect but this is still uncertain
    - Ways to improve CAM5:
      - Add quartz, calcite, feldspar for longwave effect
      - Incorporate source maps of mineralogy from Journet, Balkanski and Harrison, ACPD (2013)

- Overall, didn't make a huge difference when comparing AOD and RFE
- Overall RF from dust changes from -0.17 to -0.05Wm2 with tuned dust to +0.05 Wm2 with mineralogy
  - Adding mineralogy causes dust to be warming

- We now have infrastructure to address biogeochemical cycling of iron